

Orbit Maneuvers for In-plane Altitude Corrections for IRS Satellites – Collision Avoidance

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Abstract— Of-late many debris of defunct satellites and spent stages of rockets in the low earth orbit exist in close conjunction with the operational satellites. It has become essential to monitor space debris and their proximity with the operational satellites very closely and take quick action to carry out orbit maneuvers on the operational satellites to avoid the collision. This paper describes in-plane orbit maneuvers requirements, planning and their impact on the spacecraft orbit by considering collision avoidance maneuvers conducted for the six IRS satellites over the last three years. We further emphasize the challenges of scheduling a maneuver to IRS satellites at a very short notice taking into account routine payload operations, on-board and other operational constraints.

Index Terms—Space debris, Collision avoidance, GTS, OM, OD, IRS.

I. INTRODUCTION

Collision avoidance is a general concern in a tightly flying cluster of spacecraft with separation distances ranging from dozens to hundreds of meters [1]. There are more than 20,000 pieces of debris larger than a softball orbiting the Earth. They travel at speeds up to 17,500 mph, fast enough for a relatively small piece of orbital debris to damage a satellite. There are 500,000 pieces of debris the size of a marble or larger. There are many millions of pieces of debris that are so small that they can't be traced. With so much orbital debris, there have been surprisingly few disastrous collisions. In 1996, a French satellite was hit and damaged by debris from a French rocket that had exploded a decade earlier. On Feb. 10, 2009, a defunct Russian satellite collided with and destroyed a functioning U.S. Iridium commercial satellite. The collision added more than 2,000 pieces of trackable debris to the inventory of space junk. China's 2007 anti-satellite test, which used a missile to destroy an old weather satellite, added more than 3,000 pieces to the debris problem.

Space debris encompasses both natural (meteoroid) and artificial (man-made) particles. Meteoroids are in orbit about the Sun, while most artificial debris is in orbit about the Earth. Hence, the latter is more commonly referred to as orbital

debris. Orbital debris is any man-made object in orbit about the Earth which no longer serves a useful function.

At present, ISRO controls twelve Low Earth Orbit remote sensing satellites, of which seven are with imaging payloads, two with radar imaging payload and remaining three are scientific and communication application. On a routine basis payload programming is carried out to deliver products by imaging user defined area of interest. In order to have a standard interface with users for payload programming purposes, satellite ground traces are defined in terms of path-row scheme (reference path or ground trace) for a given day for nominal altitude of the satellite and the calendar is made available at user site for planning payload ahead of time. The user specified requests come in the form of this path-row pattern. Due to atmospheric drag, altitude of the spacecraft decreases leading to drift away from the reference ground trace. Maximum allowable ground track shift (away from the reference path) is determined based on the image overlap requirements from adjacent ground tracks for the purposes of mosaicking. Usually a Ground Track Shift (GTS) is within ± 1 km from the nominal path, equivalent to ± 112 meter change in altitude from the nominal altitude, is maintained to provide better target accuracy. However, the GTS varies satellite to satellite.

ISRO takes the threat of collisions with space debris seriously and has a long-standing set of guidelines on how to deal with each potential threat. These guidelines specify when the expected proximity of a piece of debris increases the probability of a collision enough that evasive action or other precautions to ensure the safety of the satellite are needed. When predictions indicate that the debris will pass close enough for concern and the quality of the tracking data is deemed sufficiently accurate, mission control centers work together to develop a prudent course of action.

Sometimes these encounters are known well in advance and there is time to change the orbit slightly, known as a "debris avoidance maneuver" to keep the debris outside the collision thread region of the satellite. Debris avoidance maneuvers are planned when the probability of collision from a conjunction reaches the set limits. If the probability of collision is greater than 1 in 1000, a maneuver will be conducted if it will not result in significant impact to mission objectives. If it is

greater than 1 in 1000, a maneuver will be conducted unless it will result in additional risk to the satellite. Debris avoidance maneuvers are usually small and occur from one to several hours before the time of conjunction. Several collision avoidance maneuvers with the spacecraft have been conducted during the past decades.

This paper is divided into three sections. Section II discusses spacecraft collision awareness. In section III, avoidance strategy via Orbit maneuver planning to IRS satellites is illustrated and lastly concluding discussion has been derived.

II. SPACECRAFT COLLISION AWARENESS

In this section, general satellite collision awareness with any space debris object is described.

Amid the calls for removal of space debris, spacecraft controllers face the tough reality of staying away from these “uncontrolled flying objects”. The awareness has certainly increased over the years, and efforts are being made to avoid leaving debris in LEO and GEO rings; nevertheless, with more satellites being launched, more debris accumulates from launch vehicle remains and satellites drifting after fatal anomalies.

There are three ways of the proactive approach. First, through constant monitoring of close approaches between any of our satellite and debris that may result in an avoidance action. Second, by relocating satellites with sufficient radial separation to minimize risk of close approach with other LEO or GEO satellites. Third, by respecting Inter-Agency Space Debris Coordination Committee (IASDCC) guidelines for satellite deorbiting and thereby any further accumulation of debris in the ring.

III. AVOIDANCE STRATEGY TO IRS SATELLITES

In this section, we discuss the collision avoidance strategies conducted for the IRS satellites.

Many debris of defunct satellites and spent stages of rockets in the Low Earth orbit exist in close conjunction with the operational satellites. To carry out the proximity analysis of the space object, space object proximity analysis (SOPA) team of VSSC Trivandrum computes the conjunctions between the space debris and the IRS satellites, using the state vectors of IRS satellites as an input. Orbit determination (OD) data of the satellite is used for the analysis with respect to the two line element (TLE) of the space debris. If the probability of the collision exceeds the threshold of 1 in 1000 and the close conjunction is within 100 m, an orbit maneuver (OM) is planned.

Based on the variation of semi-major axis method, timing of collision avoidance maneuver and change of the collision probability by the thrust direction at the expected collision timing, a collision avoidance maneuver is planned [3]. Generally, a collision avoidance method is chosen to increase the semi-major axis through the in-track velocity increment, due to less consumption of fuel. Sometimes only in-track velocity increment may not be sufficient to satisfy the allowable collision probability. In such scenario, velocity increment is required in all the three directions namely radial, in-track and cross-track to satisfy the allowable collision probability.

Scheduling such a collision avoidance maneuver to IRS satellites at a very short notice taking into account of routine payload operations, on-board constraints and visibility constraints is a challenging task. ISTRAC team schedules the payload of the following day, say T of the specified satellite at T-1 day and uplink of commands are executed in telemetry and tele-command (TTC) visibilities. Usually before 4 to 5 hours, SOPA team provides the collision information of any particular satellite with the specific space debris object along with the probability of collision. At such short notice time, a maneuver has to be planned to reduce the probability of collision and maneuver commands to be generated. Thus, the time constraints exist for the flexibility of generation and uplink of commands for collision avoidance maneuver and cancellation of payload operation, if it clashes with burn duration.

Accordingly, the following two cases are of interest to get a picture of response time to collision warnings:

1- A collision warning arrives time-wise before or early in an uplink cluster so that the orbit maneuver can be scheduled to the satellite in the same visibility.

2- A collision warning arrives time-wise late in a visibility cluster or after so that the orbit maneuver can only be scheduled to the satellite in the following visibility.

In either of the two cases a certain prerequisite has to be performed before the burn maneuver can be scheduled for the satellite. Firstly, the orbit position for the burn and the Δv required has to be evaluated. There is a tradeoff for the selection of orbit position of burn (i.e. maneuver time) and Δv . If burn time is selected near to the collision point, there will be requirement of large Δv to maintain the allowable separation between the satellite and debris. Secondly, to carry out in-track velocity change thruster burn should be tangential to the orbit. Hence, before the burn starts, time thrusters have to be aligned parallel to the in-track velocity vector (OM attitude).

To satisfy this requirement, the knowledge of the satellite orientation and mounting of thrusters in the satellite body frame is essential. Presently, based on application and design, IRS satellites are having two different types of attitude pointing. Satellites like Cartosat-1, Oceansat-2, Risat-1 etc.

are the Earth pointing satellites where pointing of yaw axis is towards the Earth center, pitch axis points towards negative orbit normal and roll axis along the velocity as shown in Fig.1. Eight thrusters are pointing towards negative roll vector with a canting of 30 degree towards the roll axis. This configuration provides torque about all axes when fired individually or pairs and translation motion when four or eight thrusters are fired simultaneously.

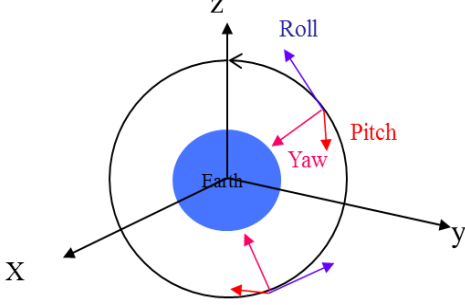


Figure 1: Earth pointing frame.

Cartosat-2 series are the type of the Sun pointing satellites where pitch axis points towards negative Sun vector; roll towards velocity direction and yaw forms the triad as shown in Fig.2. Thrusters are pointing towards negative yaw vector with a canting of 30 degree towards the yaw axis.

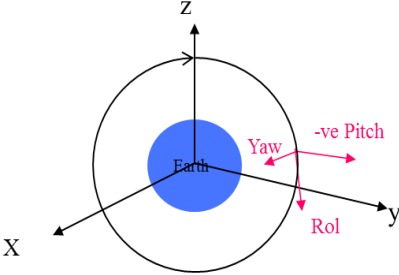


Figure 2: Sun pointing frame.

To reorient the satellite from any of these orientations to OM attitude, attitude transformation matrix is used on-board. Hence, to perform a maneuver, body attitude has to be aligned from its current attitude to OM attitude thereby aligning thrusters before the burn (pre-rotation). The burn attitude is maintained during the burn and subsequent to burn, reverse attitude maneuver is initiated to achieve the nominal attitude. To serve this purpose on-board orbit maneuver (OM) sequencer is used. OM sequencer is a program which executes specific operation at the specified time delay from the start of sequencer. Based on OM requirements, OM sequencer parameters are configured by the ground command. The OM sequencer type is selected based on the direction of change in velocity (in-track or cross-track or radial velocity increment or decrement). Using this procedure, OM sequencer carries out the forward rotation by employing this transformation matrix for attaining the burn attitude. The rotation duration is

computed based on the control system parameters, inertia of the body and maximum rate allowed. The rotation duration, thrusters' selection, burn duration etc. are some of the parameters that need to be generated and uplinked for the OM sequencer.

The orbit maneuver done for collision avoidance changes the altitude, which affects the ground track of the satellites. Ground track shift (GTS) is the amount of drift of the current orbit from the reference orbit crossing the equator eastward or westward. Therefore, at the earliest, a GTS correction maneuver should be planned to maintain the GTS within the specified limit and to satisfy the payload operation requirements. Fig. 3 shows the ground track shift boundaries which are normally maintained to satisfy the mission requirement. The value of $\pm\Delta\lambda$ is chosen based on application. Normally, when GTS reaches $+\Delta\lambda$ value, a maneuver will be scheduled to change the GTS rate bringing it back within limit.

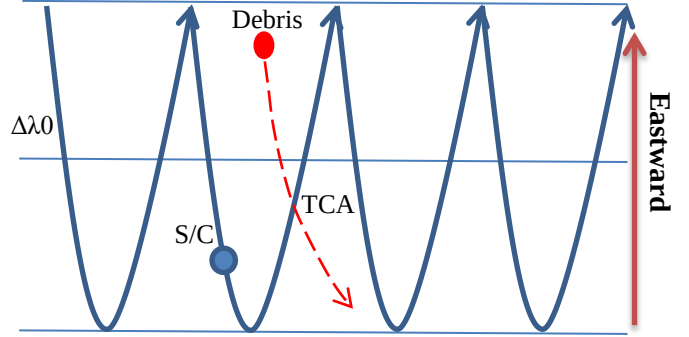


Figure 3: Ground track shift boundary.

In case, if requirement comes to schedule a maneuver for collision avoidance, GTS rate changes based on Δv due to which GTS may go out of boundary in very short time span. To bring GTS back within the boundary, a normalization maneuver has to be carried out. Due to GTS shift, the target accuracy of the scheduled payload operation during the time interval between collision avoidance maneuver and normalization maneuver gets affected. Therefore, the optimization between selection of ΔV and timing of maneuvers is required, so that one can get allowable safe distance between satellite and debris and hence, less number of payload operations gets affected.

ISRO has frequent satellite conjunction assessments for its entire maneuverable spacecraft in LEO to avoid accidental collisions with resident space objects. From 2011, ISRO has conducted 10 collision avoidance maneuvers for the six IRS satellites: Cartosat-1, Oceansat-2, Cartosat-2, Cartosat-2B, Meghatropiques-1, and IRS-P6 which are shown in Table 1. From the Table 1, we observe that if the close conjunction distance is less than 1 km, then collision avoidance analysis is

carried out resulting maneuver planning. Also normalization maneuver plan has to be planned in such a way that the close proximity of the threat does not exist. This procedure has been adopted for all IRS satellites.

Table 1: Collision avoidance maneuvers conducted from 2011 to till date for IRS satellites

Sl. No	Collision Date and Time (U.T.)	Collision Object	Spacecraft	Close conjunction distance	OM Details(To Avoid Collision)				OM Details(Normalization)		
					Date	Time (U.T.)	Δv (m/s)	Post OM Δa (m)	Date	Time (U.T.)	Δv (m/s)
1	11-12-2013 20:51:00.	SL 14 R/B	Cartosat-01	44 m	11-12-2013	16:28:00	0.07	139	13-12-2013	06:34:00	-0.07
2	30-9-2013 16:20:44	SL-16 Debris	Oceansat-2	84 m	30-09-2013	14:27:00	0.05	809	09-10-2013	09:00:00	-0.046
3	20-09-2013 22:18:58	Fengyun-1C Debris	Oceansat-2	37m	20-09-2013	18:28:00	0.10	551	24-09-2013	08:04:32	-0.12
4	18-07-2013 05:52:20	COSMOS 2251	Cartosat-2	1.6 km	18-07-2013	03:44:00	0.10		19-07-2013	14:55:00	-0.10
5	25-05-2013 23:44:00	Fengyun-1C Debris	Meghatropiques-1	10 km	OM was planned on 25-05-2013 at 13:13:00 U.T. After analysis it was found that the conjunction distance was greater than 1km. Hence, OM was cancelled.						
6	24-05-2013 01:36:00	COSMOS 2251	Cartosat-2	After analysis it was found that the conjunction distance was greater than 1km. Hence, No OM was carried out.							
7	03-10-2013	PEGASUS	Cartosat-2	After analysis it was found that the conjunction distance was greater than 1km. Hence, No OM was carried out.							
8	03-10-2013 01:48:50	SL-14 R/B	Cartosat-2	After analysis it was found that the conjunction distance was greater than 1km. Hence, No OM was carried out.							
9	11-01-2012 14:51:00	RAPIDE Y-4	Cartosat-2B	After analysis it was found that the conjunction distance was greater than 1km. Hence, No OM was carried out.							
10	06-08-2011 13:09:44	DMSP 5D-2 F11D	IRS-P6	95 m	05-08-2011	17:17:28	0.01	95	08-08-2011	17:56:57	-0.01

CONCLUSIONS

In this paper, we have discussed space debris collision awareness and avoidance strategies for the Indian Remote Sensing satellites. Space Object Proximity Analysis team takes state vector of the spacecraft from the flight dynamics operations group of ISTRAC and TLE elements as an input to carry out the proximity analysis of the space object with the spacecraft, and sends the details to ISTRAC team. If the probability of the collision exceeds the threshold of 1 in 1000 and the close conjunction is within 100 m, an orbit maneuver is planned to avoid the close conjunction with the predicted space debris. A normalization OM is also carried out in order to maintain the spacecraft Ground Track Shift within the specified limit. Of late even the post maneuver

elements of GTS control maneuver is checked for the close proximity of debris. If any threat is observed, GTS control maneuver strategy is modified to avoid the collision.

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